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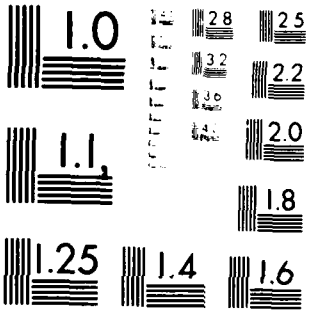

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SEAMLESS COLLAPSIBLE FUEL TANKS

Final Report: Phase II
Contract No. DAAK70-80-C-0045

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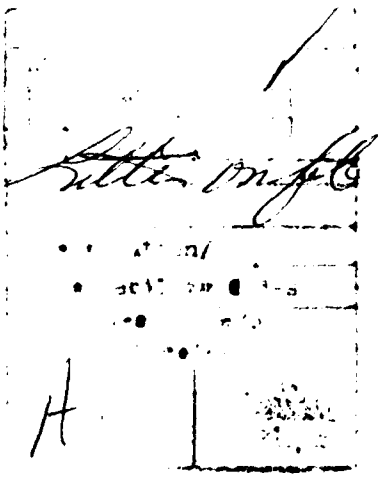

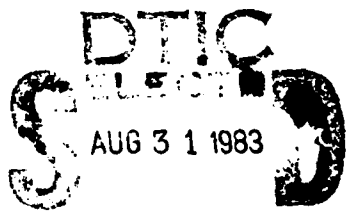

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Report DAAK70-80-C-0045

SEAMLESS COLLAPSIBLE FUEL TANKS

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Dedham, Massachusetts 02026

July 1983

Final Report: Phase II

The views, opinions and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documents.

Prepared for

MERADCOM
Fort Belvoir, VA 22060

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A131933	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Seamless Collapsible Fuel Tanks		5. TYPE OF REPORT & PERIOD COVERED Final Report: Phase II March 1982 - March 1983
		6. PERFORMING ORG. REPORT NUMBER G80143
7. AUTHOR(s) N. J. Abbott R. E. Erlandson		8. CONTRACT OR GRANT NUMBER(s) DAAK70-80-C-0045
9. PERFORMING ORGANIZATION NAME AND ADDRESS Albany International Research Co. 1000 Providence Highway Dedham, MA 02026		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Phase II
11. CONTROLLING OFFICE NAME AND ADDRESS MERADCOM Fort Belvoir, VA 22060		12. REPORT DATE July 1983
		13. NUMBER OF PAGES 10
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) DCASMA Boston 495 Summer Street Boston, MA 02210		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document has been approved for public release and sale; its distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

tubular weaving, seamless tanks, pillow tanks, fuel resistance, water resistance, latex coatings, nitriles, urethanes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Twenty-Three by twenty foot (lay flat) pieces of tubular fabric was coated with polyurethane and fabricated into two 7500-gallon fuel tanks. The tanks were shipped to Arizona for filling and exposure testing.

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Preface

The work described herein comprised Phase II of Contract No. DAAK70-80-C-0045, issued by MERADCOM, Fort Belvoir, VA to Albany International Research Co., Dedham, MA. Charles Browne was the Contracting Officer's Representative responsible for the technical monitoring of the work. Senior staff at Albany International Research Co. who were responsible for the work were Norman J. Abbott, Associate Director, Robert E. Erlandson and Robert E. Sebring, Senior Research Associates. Fabric weaving was done at Albany International Felt Division, Albany NY under the supervision of Eric Romanski, Senior Engineer.

Seamless Collapsible Fuel Tanks

Final Report: Phase II

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Introduction

Weaving of the tubular fabric to be used for manufacturing two seamless collapsible fuel tanks was successfully completed in Phase I of this program. This produced tubular fabric pieces which were 47 feet in circumference or 23-1/2 feet in lay-flat width. In order to make the tanks, lengths of 20-1/2 feet were cut from this fabric, because this was the largest piece which could be coated in tubular form, at that time.

Before the coating was done, a new coating range became available in an Albany International Felt Division plant in Tumwater, WA, which made it possible to eliminate the need for an aqueous-based coating system. As has been described in the final report for Phase I of this work, this need arose because of a lack of adequate ventilation in the coating range in Albany, NY, which was originally scheduled for use in this project. The Tumwater range was built to accommodate the use of two-component urethane coatings, and was regularly used for Adiprene L-300 coating systems. Because Adiprene L-100, closely related to L-300, had been evaluated in Phase I and proved to be potentially better than the acrylonitrile latex which had been selected for use, it was deemed desirable to take the time to evaluate Adiprene L-300, since it had now become possible to use such a coating system.

Urethane Coating Development

The coating formulation which was used was:

Part A

Adiprene L-300	100 parts
Santicizer 711 (DOP)	10 parts

Part B

Caytur 21 (curing agent)	21.3 parts
Pigment Dispersion 4705B	0.67 parts
Pigment Dispersion 4122B	0.33 parts

Parts A and B were mixed and degassed separately, part A was heated to 70°C, and the two parts were mixed together and degassed prior to casting test slabs.

Test results on these slabs were:

Coating Strength:	2355 psi at 397% elongation
Coating Tear Strength:	231 lb/in
Shore A Hardness:	80
Volume Swell in Fuel C:	approximately 40%.

These values were sufficiently encouraging to proceed with coating some of the woven nylon tank fabric on both sides, giving a final coated fabric weight of 48 oz/yd^2 (37 oz/yd^2 total coating weight). Adhesion tests were run, giving the following results:

Condition	Test Value		Minimum Requirement	
	lb/in.	% of original	lb/in.	% of original
initial adhesion	70	--	20	--
after water immersion (14 days at 160°F)	50	71	21	30
after fuel immersion (14 days at 160°F)	33	47	28	40

These values were all higher than the minimum target requirement, and it was decided to proceed with the fabric coating, which was done as described below.

Compound Preparation

As an aid to controlling the coating formulation proportions and ensuring absence of moisture, a LIM (liquid injection molding) machine was sent from the AI Precision Components Division in Middletown, CT to the Tumwater plant.

A weighed amount of Component A, containing Adiprene L-300 and DOP, was poured into the large tank of the LIM machine, while a proportionate amount of Component B, containing the Caytur 21 and pigment, was poured into the small tank. Both compoments were degassed by vacuum for several hours prior to use. After degassing, nitrogen was bled into each of the tanks to keep the components totally dry.

The components were pumped out of the two tanks in the correct proportions by two gear-driven metering pumps. They were blended in a mixing chamber by an air-driven mixer and delivered into a bucket for coating. This procedure ensures (a) that the formulation proportions are maintained within very narrow limits at all times, (b) that there is no moisture present to interfere with obtaining a good cure, and (c) that wastage is kept to a minimum because only as much material as is actually needed at any one time is mixed. Otherwise the components are stored separately under a nitrogen atmosphere, and can be withdrawn and used safely over a period of days or even weeks. The amount which we weighed out at the first of the week was sufficient to supply our needs for the whole week.

The rheology of the coating formulation proved to be ideal for our needs, giving excellent penetration into the fabric without appreciable bleed-through. The viscosity remained stable in the bucket for periods up to two hours or more, so that it was very well suited to what must be viewed as an experimental undertaking.

Coater

The coater itself consisted of two 3-foot diameter rollers which could accommodate a continuous fabric belt under a tension controlled by separation of the rolls. The coating was spread onto the fabric surface by a 4-inch diameter bar of circular cross-section which was mounted over one of the rollers. The surfaces of the roller and bar were precisely ground so that the spacing between them was controllable to $\pm$0.001". The fabric was traversed under the bar at a speed of 2 ft/min, and under an 8-foot wide bank of infrared lamps operated at a controlled voltage. Operating conditions are specified as voltages applied to the heating lamps for the time being, since temperature measuring equipment was not available.

Fabric Penetration

Initial trials with a 7-foot wide test strip indicated that a problem existed because of a large number of broken filaments in the warp yarns, particularly within an area extending about two feet either side of the woven edge of the tube, though to a lesser degree they were scattered over the whole surface. In addition, there were small clumps of trash entrapped on both fabric surfaces. Both of these types of surface non-uniformity made it impossible to coat uniformly. In bar-over-roll coating, uniformity

of the coating is critically dependent upon a uniform fabric thickness and planar surfaces.

In order to correct these surface irregularities, the fabric was singed and vacuumed. The singeing was done by traversing the fabric at a speed of about 90 feet per minute past a linear gas flame. The vacuuming was done with a foot-long linear nozzle on a commercial vacuum cleaner, while the fabric was moving at this same speed. This was done on both sides of the fabric, and the resulting surface was smooth enough to obtain a reasonably uniform coating, though the locations of each of the surface irregularities was still visible as a pock-mark in the coated fabric. In spite of the resulting mottled appearance, the fabric was thoroughly covered with coating, and was judged to be acceptable for manufacture of a prototype tank.

Coating Procedure

The following settings were used to coat the fabric using a traverse speed of 2 ft/min:

Pass No.	Blade-to-Fabric Clearance (mil)	Heater Voltage
1	4	275
2	4	275
3	11	275
4	18	285
5	18	285

It was estimated that this added about 15 mils of coating to the fabric. The tube was then turned inside out on the rolls, and exactly the same coating procedure was used on the other side of the fabric.

Fittings

A study of adhesive systems for bonding the coated fabric to the tank hardware was undertaken using aluminum plate which had been anodized and colored in accordance with MIL-A-8625, Type II, Class 2, as required in the specifications for hardware given in MIL-T-52573D. This is a sulfuric acid anodizing treatment. It was quickly found that it was impossible to obtain any significant adhesion to this surface. An examination of the literature showed that good adhesion could only be maintained by removing the anodized surface, for example by sanding. Subsequent discussion of the problem with

personnel at MERADCOM revealed that this problem was well known to one of their chemists, who said that good bonding could only be achieved using phosphoric acid anodizing. Suppliers of hardware for pillow tanks apparently understood this also, for they were not anodizing the surface of their hardware, but were using a finish called Alodine 1200, as described in MIL-C-5541. This is a chromate conversion coating designed specifically for excellent adhesion of coatings and paints. It is mentioned as an alternative to anodizing in one of the hardware drawings in MIL-T-52573D (Figure 4, suction stub). All of the hardware which we ordered for the tanks which required bonding to the coated fabric was finished by the chromate conversion procedure. Other pieces which were screwed into these bonded components were anodized per MIL-A-8625, Type II, Class 2.

Potential bonding agents were tested by bonding coated fabric to the anodized plates mentioned above, which had been sanded in the bonded area. Table 1 summarizes the results of these studies.

Table 1

Bonding Agents for Aluminum/Coated Fabric Surfaces

Agent	Bonding Strength (lb/in.) initial	Bonding Strength (lb/in.) after 14 days in fuel at 160°F
Versilok 204/accelerator #4 (acrylic)	>70	10
Tycel 7002/7202 (urethane)	19	3
Chemlock 233/primer Chemlok 205 (organic polymers with isocyanate)	25	17
Bostick 7376/Boscodur #4	30	10
Adiprene L-300 (urethane)	70	25

The tank coating compound, Adiprene L-300, was selected for bonding the fittings. Although no similar tests were made with the chromate conversion finished hardware, it was evident that the adhesion obtained was at least as good as we had experienced with sanded anodized aluminum.

Tank Assembly

Mounting of the hardware and reinforcing patches, as well as sealing of the end seams, was accomplished using the standard Adiprene L-300 coating formulation as the adhesive, and supplying heat by clamping between heated metal plates. Good bonds were obtained by this technique, in which

the bonded interfaces were usually indistinguishable from the body of the coating. The end seams were formed by cutting and folding as shown in Figure 1.

No serious problems were encountered, through fabrication of a larger number of tanks would be facilitated by the construction of suitable, heated clamping jigs.

Testing of the Completed Tank

Leak testing was done by inflating the tanks with air to 0.5 psi, waiting for 30 minutes, and then reinflating to 0.5 psi and testing all bonded areas with soap solution. No leaks were found in one tank; two pinhole leaks detected at the end of the seam in the second tank were stopped by adding a surface patch of coated fabric.

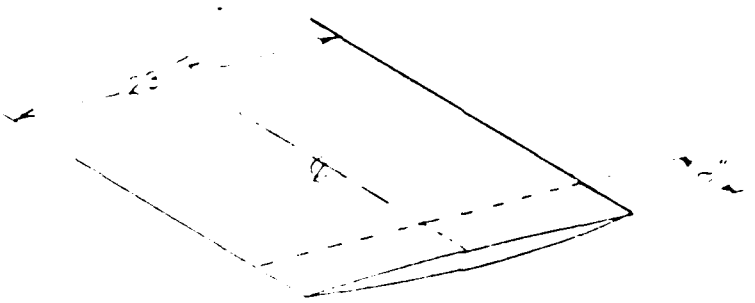
Properties of the Finished Tank Fabric

Measured properties of the coating compound, coated fabric and seams are summarized in Table 2.

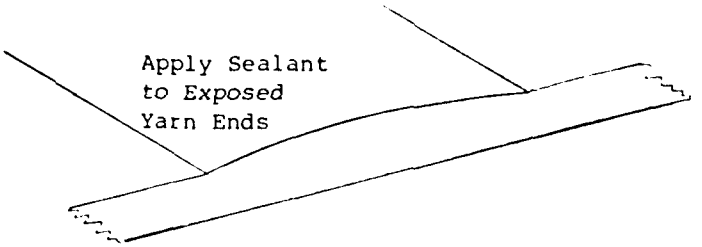
It should be emphasized again that the prime purpose of this work was to demonstrate the feasibility of a new manufacturing procedure, namely the use of wide, tubular woven fabric, and not to optimize the procedure for production of tanks to be used in the field. Consequently, the coating compound was selected primarily for convenience and general suitability, rather than for total compliance with all specifications.

Examination of the data in Table 1 will show that the initial requirements have, for the most part, been met, with the exception of the fuel diffusion rate. Over a period of time, the diffusion rate decreases and probably would meet the target requirement within about one month. However, this is a clear indication that there is slow swelling of the coating occurring, which can be expected to affect the properties. In fact, the loss in strength after 14 days in fuel at 160^{O}F is only about 50%, less than the 60% permitted in the specification. Fuel immersion has a much more serious affect on peel adhesion, however, where the loss is 87% after 14 days at 160^{O}F. Water immersion for 14 days at 160^{O} has almost no effect on the breaking strength of the coating compound, but reduces the peel adhesion by more than 90%.

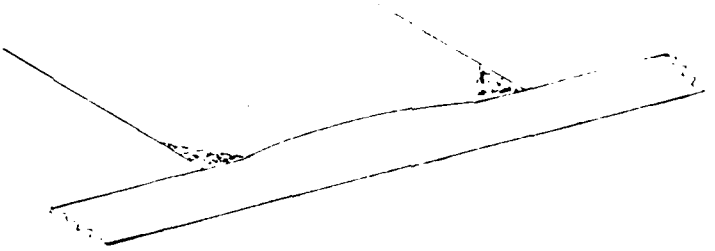
1. Cut 'T' Pattern Both Ends



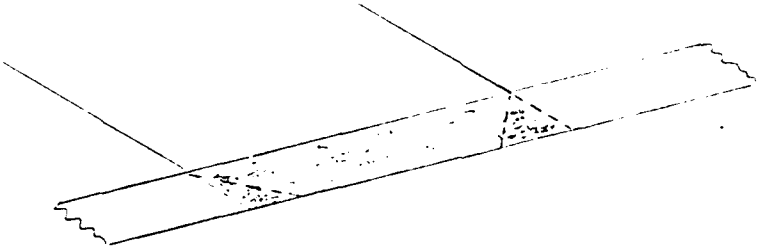
2. Fold Out Flat



3. Adhesive Bond Corners as shown



4. Fold Over End and Adhesive Bond Lap Seam as shown



5. Fold Tabs Under and Adhesive Bond as shown

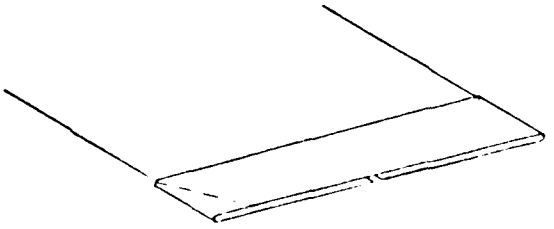


Figure 1. End Seam Construction Detail

Table 2

Properties of Tank Compound, Coated Fabric and Seams

Material	Property	Target Value	Measured Value
Coating Compounds	Tensile Strength		
	initial (psi)	1500 (min)	2165
	after 14 days in water at 160°F	600 (40%)	2120 (98%)
	after 14 days in fuel at 160°F	600 (40%)	1110 (51%)
	Ultimate Elongation (%)	300 (min)	345
	Unwashed Existent Gum	--	--
	Heptane Washed Existent Gum	--	--
Coated Fabric	Weight (oz/yd^2)	48 (max)	47
	Fuel Diffusion Rate ($oz/ft^2/24$ hr)	0.1 (max)	1.0 decreasing to 0.2 with time
	Tearing Strength warp x fill (lb)	25 x 25 (min)	35 x 32
	Breaking Strength warp x fill (lb/in.)	350 x 350 (min)	510 x 300
	Puncture Resistance (lb)	110 (min)	140
	Low Temperature Crease Resistance	no cracking, peeling or delamination	no cracking, peeling or delamination
	Blocking (4 hr at 158°F)	separation within 5 sec	separates instantly
	Coating Adhesion		
	initial (lb/in.)	20 (min)	23
	after 14 days in water at 160°F	10 or 30%	rubber tearing at >10 lb/in.
	after 14 days in fuel at 160°F	10 or 40%	rubber tearing at >10 lb/in.
Seams	Breaking Strength		
	initial (lb/in.)	350 (min)	360-510
	after 14 days in water at 160°F	280 (min)	190
	after 14 days in fuel at 160°F	315 (min)	305
	Dead Load Shear Resistance	0.10" (max)	0
	Peel Adhesion		
	initial (lb/in.)	25 (min)	23
	after 14 days in water at 160°F	10 or 40%	2 (9%)
	after 14 days in fuel at 160°F	15 or 50%	3 (13%)

In general, the compound used for coating has met the target requirements. However, under conditions in which water or fuel is able to penetrate the seamed area, serious loss in seam adhesion can occur. This is a problem which would require improvement before any manufacturing run was commenced.

Problems which Arose and Possible Solutions

(1) The broken filaments which had to be singed off during coating were the result of weaving tensions, particularly those warp stresses which arose in the neighborhood of the temples. The temples are special plates which ride inside the fabric tube at each edge in the weaving zone. The uniformity of the tubular weave at these turn-around points is largely due to the proper adjustment of the temples. It was known while the fabric was being woven that considerable warp filament breakage was occurring, and every available precaution was taken to reduce this breakage, consistent with retaining a good weave uniformity at the turn-around. The most effective means of alleviating the effects of the high tensions was to spray the warp with a solution of a lubricant. However, as we found out, this was not a totally satisfactory solution. Two means of reducing warp filament breakage suggest themselves: (a) use a more effective warp size, even if this involves the necessity of subsequently removing it by scouring; (b) use heavier filaments, even monofilaments to reduce the vulnerability of the yarns. Both of these should be investigated in any future work.

(2) During the coating of the fabric, longitudinal wrinkles developed, particularly in the center of the endless belt. These are presumed to be due to a 2-3% shrinkage of the fabric as its temperature is raised. These were essentially eliminated initially by running the uncoated fabric under the heating lamps for a few revolutions. However, as coating built up and the fabric became stiffer, the wrinkles reformed and created ridges which could not be uniformly coated. There are no facilities at present on the coater to permit widthwise tensioning of the fabric.

Another possible solution to the wrinkling problem would be to weave the base fabric from monofilament or plied monofilament polyester in the warp direction (which would become the widthwise direction of the belt being coated). The added stiffness combined with the use of a thermally stable fiber, should completely eliminate lengthwise wrinkles.

(3) Because of the added stiffness when one side is coated, it proved to be extremely difficult to turn the fabric inside out. This would probably be even more difficult if the fabric were stiffened by using monofilaments. It is probably worthwhile to consider an alternative to the use of a woven tube of fabric. If the tank were to be made from wide woven flat fabric, there would be one additional bonded seam required. However, if this were positioned to run along the center of the bottom of the tank, it would be completely protected from the weather and, furthermore, would be located in an area of the tank where stresses are at their lowest. It seems unlikely that this would affect the durability of the tank in the way that the seams along the top surface do.

(4) A coating compound is needed which has better long-term water and fuel resistance than L-300, and is compatible with the limitations of the coating facility. A wide range of urethanes is available, some of which have excellent water and fuel resistance.

Conclusions

The feasibility of making a seamless fuel tank has been demonstrated. Facilities exist which are capable of weaving and coating very wide fabric, either in flat or tubular form. Although problems were encountered, they appear to have relatively simple solutions, and the prospects of producing a superior product on a commercial scale are excellent.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